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On many occasions, such as giving directions, spatial situations are described in words rather than depicted. In comprehending such descriptions, people form mental representations of the situation described by the discourse as well as representations of the text. This project investigates spatial mental models induced by words for large-scale and for immediate environments. The results simultaneously illucidate spatial thinking, text comprehension and text construction. The experiments using large-scale environments focus on the comprehension and production of various kinds of descriptive text. The experiments using immediate environments focus on on-line use of spatial mental models and updating under changes in point of view. New research is expanding both projects, including investigations of construction of mental models.

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Induced Pictorial Representations

Barbara Tversky
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Summary. On many occasions, such as giving directions, spatial situations are described in words rather than depicted. In comprehending such descriptions, people form mental representations of the situation described by the discourse as well as representations of the text. This project investigates spatial mental models induced by words for large-scale and for immediate environments. The results simultaneously illucidate spatial thinking, text comprehension, and text construction. The experiments using large-scale environments focus on the comprehension and production of various kinds of descriptive text. The experiments using immediate environments focus on on-line use of spatial mental models and updating under changes in point of view. New research is expanding both projects, including investigation of construction of mental models.

I. Large-scale Environments: **Route and Survey Descriptions.**

A. *Perspective-free Spatial Mental Models*. An informal examination of geography and guide books reveals two common ways to describe environments: *survey*, where the viewpoint is from above, and landmarks are described relative to one another in terms of north, south, east, west; and *route*, where the viewpoint is within the environment, and landmarks are described relative to the position of a moving observer in terms of left, right, front, and back. This research has been in collaboration with Holly A. Taylor, currently a graduate student in psychology in her final year. This project and all of the subsequent projects have also involved undergraduate psychology majors, too numerous to name. Typically, two to six undergraduates are involved in any project. In the first set of studies (Taylor and Tversky, 1992), subjects read route or survey descriptions of up to four environments (resort area, town, convention center, zoo). Accuracy and reaction time to answer verbatim and inference statements from both perspectives indicated that both types of descriptions appear to induce the same spatial mental model. Contrary to previous work, the mental models subjects constructed in four experiments did not seem to preserve the perspective of the description. Rather, they were more abstract, and seemed to incorporate the spatial relations among landmarks in a perspective-free manner, like a structural description, allowing the taking of many specific perspectives.

B. *Descriptions: Organization*. This initial project has spawned many others, including two investigations of subject-produced descriptions of environments. In the first (Taylor and Tversky, in press), subjects studied maps of three environments, and from memory produced both descriptions and drawings of them in counter-balanced order. The order of drawing or describing landmarks was used as an index of the mental organization of the environments in a variety of data analyses. There was good concordance in ordering landmarks within subjects across drawing and describing tasks and across subjects for both tasks, indicating agreement on the organization of the environments. Descriptions were more tightly ordered than depictions.

consistent with the need for a description to be coherent from start to finish. Analyses of the organization of specific environments revealed hierarchies based on both spatial and functional characteristics of the environments, and sequencing based on conventional orders as well as spatial and functional aspects of the environments.

C. *Descriptions: Perspective.* The second investigation of subject-produced descriptions, also with Taylor, has focussed on perspective. There have been claims in the psycholinguistic literature that people take a consistent perspective in describing environments, overwhelmingly a route perspective. Contrary to those claims, we found that subjects frequently take survey perspectives, and also frequently alternate or mix perspectives. Interestingly, in examining hundreds of protocols, we have not found use of yet another descriptive technique. In an effort to discover what determines descrilption perspective, we systematically varied a number of spatial features of environments: landmarks on several size scales; multiple vs. single paths through the environment; whether the environment was enclosed or open; whether the environment was large- or small-scale. There were more survey descriptions when the maps had landmarks on several different size scales (e. g., mountains, roads, buildings) and multiple paths in the environment. The other variables had no effect on relative frequency of route and survey descriptions. Another study in this series examines in detail the linguistic devices used in constructing route and survey descriptions. These two perspectives can be used to describe situations other than spatial situations, so they have greater generality. The data analysis for this project has required innovation, as there are few prior models. It is almost complete, and the manuscript is in preparation.

D. *Descriptions: Time.* We often need to construct mental models of time as well as of space. For example, in supervising a group of workers, we need to keep track of what each worker is doing throughout a day. A mental model of such information could be organized around the characters or around time periods, or around both. Taylor and I have begun investigations of mental models of time, borrowing many of the techniques we used in investigating mental models of space. In the first experiment of the series, subjects read narratives either organized by character or organized by time slots, and later answered questions emphasizing one organization or the other. Subjects appeared to prefer to organize around character. In a second study, the events themselves were organized around a common theme, in some cases corresponding to character and in other cases corresponding to time. As before, narratives were organized either by character or by time. In this study, the organization of the events prevailed, whether it corresponded to character or to time. Place is also a good organizer, and subsequent studies in this series will compare place to character in organizing events. These experiments constitute Taylor's Ph. D. dissertation, to be completed summer, 1992.

E. *New Project: Optimal Order of Information.* In either route or survey descriptions, information regarding path, direction, and distance is conveyed. In English, these three pieces of information can be freely ordered. For examples, consider these route descriptions: To get to the Post Office, go right on Main two blocks; go on Main right two blocks; go two blocks right on Main, and so on. Or their survey analogs: The Post Office is north on Main two blocks; is on Main north two blocks; is two blocks north on Main, and so. Three interrelated questions are of interest. Do people have a preference for producing path, direction, and distance information in a particular order? Is comprehension of that information better in one order or another? Does

the order in production and comprehension interact with the type of description, route or survey? Graduate student Deborah Tatar and I have begun a project investigating the microstructure of route and survey descriptions in comprehension and production.

F. *New Project: Spatial Inferences in an Interactive Environment.* Our own research as well as that of others indicates that people can learn environments from well-constructed descriptions. Graduate student Scott Mainwaring is constructing a computer world, which, like an adventure game, is learned and explored only by description. When this environment is completed, we plan to study a number of problems in spatial cognition. First, we will be able to see how people learn new routes based on previous information and spatial inferences, varying the difficulty of both. Second, we will be able to study the nature of the spatial mental models formed by introducing probes for direction and distance information into the task.

II. Immediate Environment: **Spatial Frameworks.**

A. *Internal Spatial Framework.* How do we keep track of a described world immediately around a character as that character navigates the world? This project was begun with Nancy Franklin, then a graduate student in psychology, currently an Assistant Professor at the State University of New York-Stony Brook. In the first set of studies, we (Franklin and Tversky, 1990) proposed that readers construct a mental spatial framework based on the three body and append objects to that. According to the spatial framework analysis, the relative accessibility of the three axes depends on characteristics of the body as well as the relation of the body to the perceptual world. For an upright observer, the head/feet axis is most salient: it is asymmetric, and it is correlated with the only asymmetric axis of the world, the vertical axis produced by gravity. Next is the front/back axis, which has important biological, perceptual, and functional asymmetries. Least salient is the left/right axis which has no prominent asymmetries. When the observer reclines, no body axis corresponds to gravity, so salience depends only on the body axes themselves. In that case, the asymmetries of the front/back axis dominate those of the head/feet axis, and it becomes most salient. This analysis received support from five experiments. In each experiment, subjects read descriptions of scenes in which "you" were surrounded by objects in all directions and periodically moved to face one object or another. At each facing, subjects were probed for the objects in all directions, and the reaction times to access them corresponded to the spatial framework predictions.

B. *External Spatial Framework.* Subsequent research has studied interesting variations of the basic scene, that of an observer surrounded by objects. In one variation, studied in collaboration with David J. Bryant, then a graduate student, currently an Assistant Professor at Northeastern University, the observer was external to a scene, of two types, a cubic array of objects or another character surrounded by objects (Bryant, Tversky, and Franklin, 1992). In the external case, the mental framework depends more on properties of the world than those of the body. The vertical axis is again most salient as it is the only asymmetric axis of the world. The front/back axis is next, because from the observer's external view point, objects to the front appear larger and more distinct, and may occlude objects to the back. The left/right axis has no apparent asymmetries. Several experiments yielded data supporting the external spatial framework as well as a critical difference between external and internal versions. In the internal

case, objects to the back are behind the observer, whereas in the external case, objects to the back are in front of the observer, but farther away than those to the front. This would lead one to expect faster reaction times to front than back in the internal case, but not in the external case, and that pattern obtained. Other studies in the same series demonstrated that readers take the point of view of an internal inanimate object surrounded by objects when queried from the point of view of the object.

C. *Probing for Directions.* Up until now, we have given subjects direction terms, and they have provided object names. According to the spatial framework analysis, the same pattern of data should appear if subjects are given objects and probed for directions. Bryant and Tversky (1992) obtained corroborative evidence for both external and internal situations.

D. *Two Points of View.* What would happen if there were two observers in the described scene, and subjects were asked to respond from each of their points of view? According to previous results, readers take the point of view of either a human being or an inanimate object when probed for objects from the observer's or object's point of view. These findings suggest that readers respond to two observers by taking their respective points of view in turn, yielding the spatial framework pattern of data. Along with Vicki Coon, a former undergraduate at SUNY-Stony Brook, Franklin and I (Franklin, Tversky, and Coon, in press) investigated perspective-taking in several situations with more than one possible point of view. Contrary to expectations from previous research, readers did not take the respective points of view of the two observers in most cases. Rather, as long as observers were described as being in the same scene, readers seemed to take an oblique or overhead perspective that allowed them to derive both points of view. Only when the two observers were described as in disparate settings did the spatial framework pattern of data appear, indicating that readers took the perspectives of the observers.

E. *New Project: Changing the Number of Points of View.* From the previous findings, it can be concluded that when there is one observer in a scene, readers will take that observer's point of view, but when there are two observers, readers will take a neutral point of view. What would readers do then if the scene starts out with one observer and then adds a second one, both of whose points of view are probed? Would they first adopt the observer's perspective and then switch to a neutral perspective, or would they switch between observers' perspectives? A Senior Honors student in Psychology, Jay Leahy, is currently designing experiments to answer that question.

F. *New Project: Moving Environment vs. Moving World.* In the previous studies, observers have turned and moved in the environments. A spatial situation can change when objects move rather than the observer. Because it is more common for a person to move than objects to move, it may be easier to keep track of objects when the person moves, although formally the situations can be identical. A Senior Honors student, Joe Kim, is currently designing a set of experiments to compare a moving world to a moving observer. This study will also investigate an upside-down observer, a situation we have long wanted to look at.

G. *Representing Distance, Turns, and Number of Landmarks.* For her dissertation research, Franklin investigated the mental representation of distance, turns, and number of landmarks both in mental model construction and in information retrieval. Subjects read descriptions of the assignments of a delivery truck. On the whole, turn took longer than no turn, and more landmarks and greater distance took longer than less, but the relations were not linear. Her thesis was entitled, "Constraints on Memory Search Imposed by Spatial Features of Described Scenes." Her Ph. D. was awarded in September, 1989. She is adding another experiment to this series for publication.

H. *Locating Objects from Memory or from Sight.* For his dissertation research, Bryant taught subjects environments from observation rather than from description, and then probed them from memory or from sight. Subjects observed one of two settings. In the first, they viewed a doll surrounded by objects, and responded either from the doll's internal viewpoint or the subject's external viewpoint. In the second, they were themselves surrounded by objects, standing or lying on a bench to simulate the standing and reclining positions in the descriptions. In both cases, when subjects responded from memory, the patterns of times were those predicted by the spatial framework analysis, internal or external as appropriate. Thus, spatial mental models established from description are indistinguishible from those established by experience. The patterns of reaction times for responding from sight, however, were different, indicating that spatial frameworks are not like internalized perceptions (as in imagery). These experiments were described in Bryant's dissertation, "Perceptual Characteristics of Mental Spatial Models." His Ph. D. was awarded in July, 1991. The experiments in which subjects responded from sight need to be replicated prior to publication. It turned out, interestingly, that in many cases, subjects responded from memory rather than looking. In the replications, we will be able to separate those trials in which subjects looked from those in which they responded from memory.

I. *New Project: Construction of Mental Models.* After studying on-line use of mental models, we became interested in on-line construction of mental models. Our attempts to study reading times for spatial framework tasks yielded inconclusive results. Instead, graduate student Caren Jones and I have adapted a paradigm developed by Stenning and his collaborators in which subjects are timed to read molecular statements, describing an object or a property of an object. Altogether, there are 2 or 4 objects and 2 or 4 properties. Our plan was to first replicate the Stenning results, and then enrich the task by adding spatial relations. In the meantime, the replication has turned up interesting results. The Stenning group found that reading times increased for each additional property of an object. In pilot work, we found that pattern when information was presented by property, but the opposite pattern when information was presented by object. If subjects construct mental models by creating mental objects and adding properties to them, then the task of establishing a mental object should be more time-consuming than that of adding properties. However, if subjects remember properties in a list format, then adding another property should take more time, as the entire list would be rehearsed. If this reasoning is correct, then it appears that subjects establish mental models when information is presented by object, but form lists when information is presented by property. We plan more experiments on these issues before going on to examine construction of mental models where there are spatial relations among the objects.

J. *New Project: Representations of the Body.* The spatial framework analysis is a theory of how people conceive of the space around their bodies in information retrieval. Graduate student Laura Miller and I have begun to design experiments investigating how people conceive of their bodies, by adapting the spatial framework experimental paradigm. Subjects will associate pictures to various body parts, beginning with head, feet, hands, chest, and back. The pictures will be moved, and subjects will be probed for the picture currently at various parts, under various body postures. There are many interesting variants of this task, adding left and right, adding other body parts, testing face parts, adding another person, and more. It is possible that we think about the body in the same way that we think about the space around the body, so that the spatial framework pattern will again emerge. On the other hand, conceptions of the body may be more proprioceptive, and reflect the relative proprioceptive sensitivity of the various body parts.

III. **Related Work: Spatial Distortions.**

The grant supported completion of research on systematic distortions in memory for maps and graphs. One way people remember graph lines or land masses is to remember their orientation and location relative to a frame of reference. Once something is coded in terms of a frame of reference, it tends to be remembered as closer to that frame of reference, an effect similar to anchoring or assimilation. Frames of reference may be perceptual, such as the sides of a page, or conceptual, such as the canonical axes for maps or the 45 degree line for graphs. Diane Schiano, a former post-doctoral student, later at NASA-Ames, and now at Sun Microsystems, and I showed that the same lines were distorted differently in memory depending on whether they were seen as meaningful graphs or meaningless lines (Schiano and Tversky, 1992). This work as well as other work on distortions in memory for maps and graphs was reviewed and analyzed in Tversky (1991) and (Tversky, in press b).

IV. **Related Work: Cross-cultural Graphic Representations.** The grant supported completion of a large-scale project studying graphic productions of spatial, temporal, preference, and quantitative concepts in children and adults in three cultures with different writing systems. That research revealed developmental increases apparent in all cultures in the information preserved in graphs. It also showed effects of writing on temporal concepts but not on other concepts, and of universal association of up with good or more on preference and quantitative concepts (Tversky, Kugelmass and Winter, 1991). Sol Kugelmass is a Professor in the Department of Psychology at the Hebrew University of Jerusalem, where the Hebrew-speaking and Arabic-speaking subjects were run. Atalia Winter was a student in the Master's program in Jerusalem.

Professional Personnel. The following professionals have participated in the work: Nancy Franklin, former graduate student, currently Assistant Professor at State University of New York, Stony Brook; Dr. Diane Schiano, former post-doctoral student, now at Sun Microsystems; David J. Bryant, former graduate student, currently Assistant Professor at Northeastern University; Professor Sol Kugelmass of Hebrew University-Jerusalem; graduate students Holly A. Taylor, Caren Jones, Scott Mainwaring, Atalia Winter, Deborah Tatar, and Laura Miller;

Senior Honors students Joe Kim and Jay Leahy; about 12 other undergraduates.

Dissertations. Nancy Franklin received her Ph. D. in September, 1989; her thesis was entitled, "Constraints on Memory Search Imposed by Spatial Features of Described Scenes." David J. Bryant received his Ph. D. in July, 1991; his thesis was entitled, "Perceptual Characteristics of Mental Spatial Models."

Grant-related publications.

Franklin, N. and Tversky, B. (1990). Searching imagined environments. *Journal of Experimental Psychology: General, 119*, 63-76.

Tversky, B. (1990). Where partonomies and taxonomies meet. In S. L. Tsohatzidis (Ed.), *Meanings and prototypes: Studies on linguistic categorization.* Pp. 334-344. London: Routledge.

Tversky, B. (1991). Distortions in memory for visual displays. In S. R. Ellis (Ed.) and M. K. Kaiser and A. Grunwald (Associate Editors), *Pictorial communication in virtual and real environments.* Pp. 61-75. London: Taylor and Francis.

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Tversky, B. and Hemenway, K. (1991). Parts and the basic level in natural categories and artificial stimuli: Comments on Murphy (1991). *Memory and Cognition, 19,* 439-442.

Bryant, D. J. and Tversky, B. (1992). Assessing spatial frameworks with object and direction probes. *Bulletin of the Psychonomic Society, 30*, 29-32.

Bryant, D. J., Tversky, B., & Franklin, N. (1992). Internal and external spatial frameworks for representing described scenes. *Journal of Language and Memory, 31*, 74-98.

Schiano, D. and Tversky, B. (1992). Structure and strategy in viewing simple graphs. *Memory and Cognition, 20,* 12-20.

Taylor, H. A. and Tversky, B. (1992). Spatial mental models derived from survey and route descriptions. *Journal of Memory and Language, 31.*

Tversky, B. (1992). Spatial mental representations. *Proceedings of the 1992 AAAI Spring Conference.*

Tversky, B. (In press a). Images before and behind the eye. Review of *Images and*

Understanding, edited by H. Barlow, C. Blakemore and M. Weston-Smith. *Contemporary Psychology*.

Tversky, B. (In press b). Distortions in cognitive maps. *Geoforum*.

Franklin, N., Tversky, B., and Coon, V. (In press). Switching points of view in spatial mental models acquired from text. *Memory and Cognition*.

Taylor, H. A. and Tversky, B. (In press). Descriptions and depictions of environments. *Memory and Cognition*.

Bryant, D. J. and Tversky, B. Spatial mental models from observed and remembered scenes. In preparation.

Taylor, H. A. and Tversky, B. Perspective in spatial descriptions. In preparation.

Papers presented at meetings, conferences, and colloquia:

"Cognitive Maps" presented at the Air Force Office of Scientific Research, November, 1988.

"Answering Questions about Imagined Scenes: How Do We Look?" with Nancy Franklin, presented at the 29th Annual Meeting of the Psychonomic Society, Chicago, November, 1988.

"Spatial Mental Models Induced by Narratives" presented at Columbia University Psychology Department, September, 1989.

"Induced Pictorial Representations" presented to AFOSR meeting, Alexandria, VA, November, 1989.

"Learning Environments from Survey and Route Descriptions" with Holly Taylor, poster presented at the 30th Annual Meeting of the Psychonomic Society, Atlanta, November, 1989.

"Structure and Strategy in Memory for Line Slope" with Diane Schiano, poster presented at the 30th Annual Meeting of the Psychonomic Society, Atlanta, November, 1989.

"Spatial Mental Models" Cognitive Science Seminar presented at Princeton University, April, 1990.

"Spatial Mental Models" presented at the Center for the Study of Language and Information, Stanford University, May, 1990.

"General Organizational Principles for Characterizing Observers' Perspectives in Described Scenes." with David Bryant and Nancy Franklin, poster presented at the American Association for the Study of Mental Imagery, Boston, June, 1990.

"Different Memory Representations for Space Surrounding You, Him, and It?" with David Bryant and Nancy Franklin, poster presented at the annual meetings of the American Psychological Association, Boston, August, 1990.

"Constructing, Updating, and Accessing a Representation of Described Space," by Nancy Franklin, poster presented at the annual meetings of the American Psychological Association, Boston, August, 1990.

"The Spatial Organization of Mental Models" by Nancy Franklin, colloquium presented at New York University, October, 1990.

"Spatial Descriptions and Depictions" with Holly Taylor, presented at the 31st Annual Meeting of the Psychonomic Society, New Orleans, November, 1990.

"Mental Spatial Frameworks for Different Perspectives" with Nancy Franklin, poster presented at the 31st Annual Meeting of the Psychonomic Society, New Orleans, November, 1990.

"Spatial Mental Models" presented at the Winter Text Conference, Jackson Hole, January, 1991.

"Spatial Mental Models," colloquium presented at Pomona College, February, 1991.

"Distortions in Cognitive Maps," invited lecture at Whitman College, March, 1991.

"Images, Perceptions, and Mental Models," invited lecture at the Center for the Study of Language and Information, Stanford University, April, 1991.

"Spatial Mental Models Derived from Survey and Route Descriptions" with Holly A. Taylor, poster presented at Western Psychological Association meetings, April, 1991.

"Mental Spatial Frameworks: Perspective and Organization" with David J. Bryant and Nancy Franklin, poster presented at Western Psychological Association meetings, April, 1991.

"Spatial Mental Models" with Holly A. Taylor, invited symposium at Midwestern Psychological Association, May, 1991.

"Perspective in Spatial Mental Models Derived from Text" with Nancy Franklin and Vicki Coon, invited symposium at Midwestern Psychological Association, May, 1991.

"Spatial Mental Models" invited lecture, Department of Psychology, University of California, Berkeley, October, 1991.

"Spatial Mental Models" invited colloquium, Cognitive Science Program, Wellesley College, October, 1991.

"Locating Objects from Memory or from Sight" with David J. Bryant, paper presented at 32nd Annual Meeting of the Psychonomic Society, San Francisco, November, 1991.

"Spatial Mental Representations: Are they like Images?" Invited lecture at Winter Text Conference, Jackson Hole, WY, January, 1992.

"Spatial Mental Representations" invited lecture at AAAI Spring Conference, Stanford, CA, March, 1992.